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(54) IGNITION COIL

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H01F 27/29 (2006.01)
H01F 27/32 (2006.01)
H01F 38/12 (2006.01)
H01F 5/02 (2006.01)

(52) **U.S. Cl.**

CPC ***H01F 27/325*** (2013.01); ***H01F 27/29*** (2013.01); ***H01F 38/12*** (2013.01); *H01F 2005/025* (2013.01)

(58) **Field of Classification Search**

CPC H01F 27/00–27/30
USPC 336/65, 83, 90, 92, 96, 107, 192, 336/220–223
See application file for complete search history.

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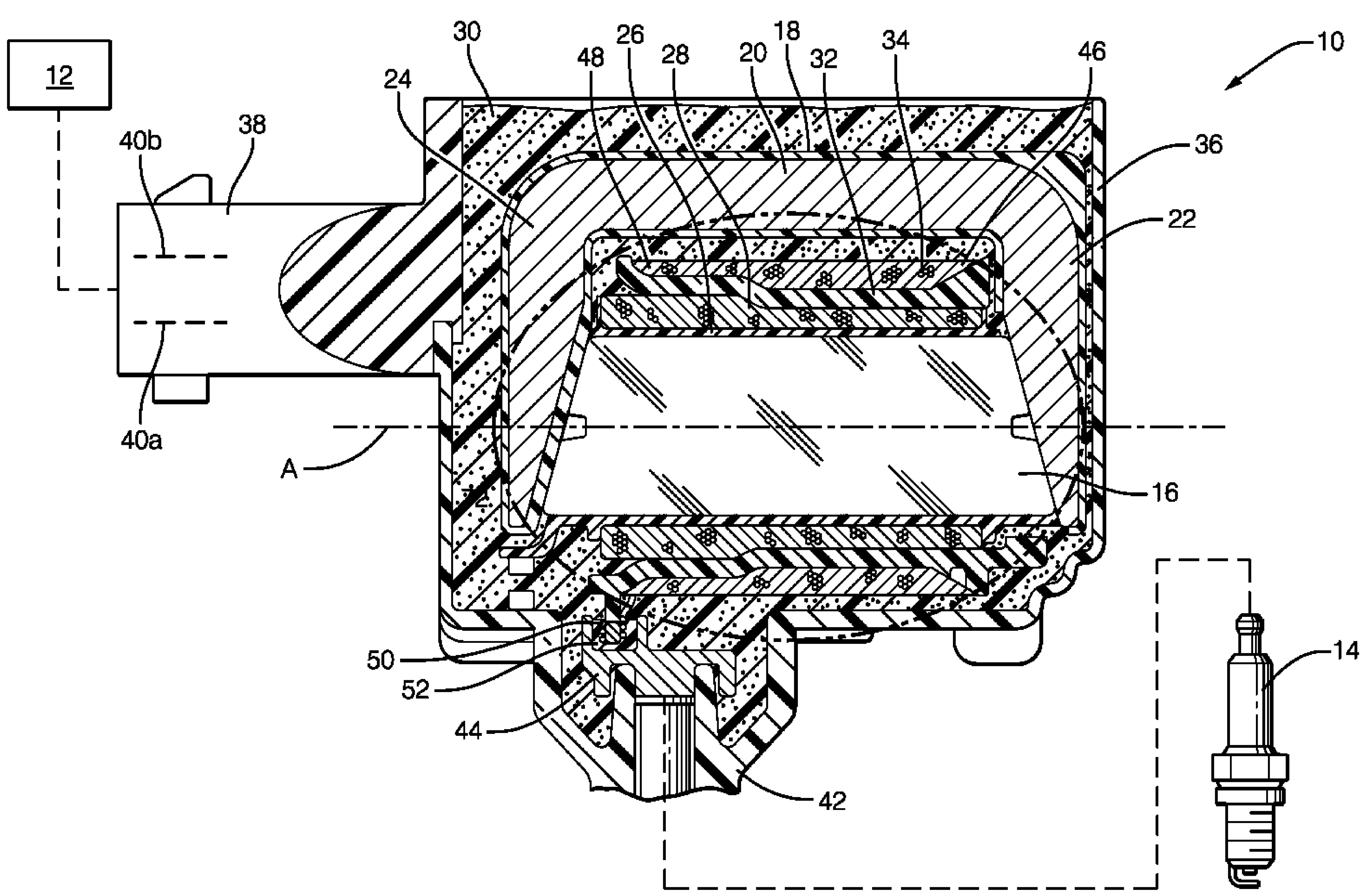
(57) **ABSTRACT**

An ignition coil for delivering a spark-generating current to a spark plug includes a magnetically-permeable core; a primary winding disposed outward of the core; and a secondary winding radially surrounding the primary winding and inductively coupled to the primary winding, the secondary winding having a low-voltage end and a high-voltage end. The secondary winding includes a secondary winding first section proximal to the low-voltage end and having a first thickness. The secondary winding also includes a secondary winding second section proximal to the high-voltage end and having a second thickness that is less than the first thickness of the secondary winding first section.

14 Claims, 2 Drawing Sheets



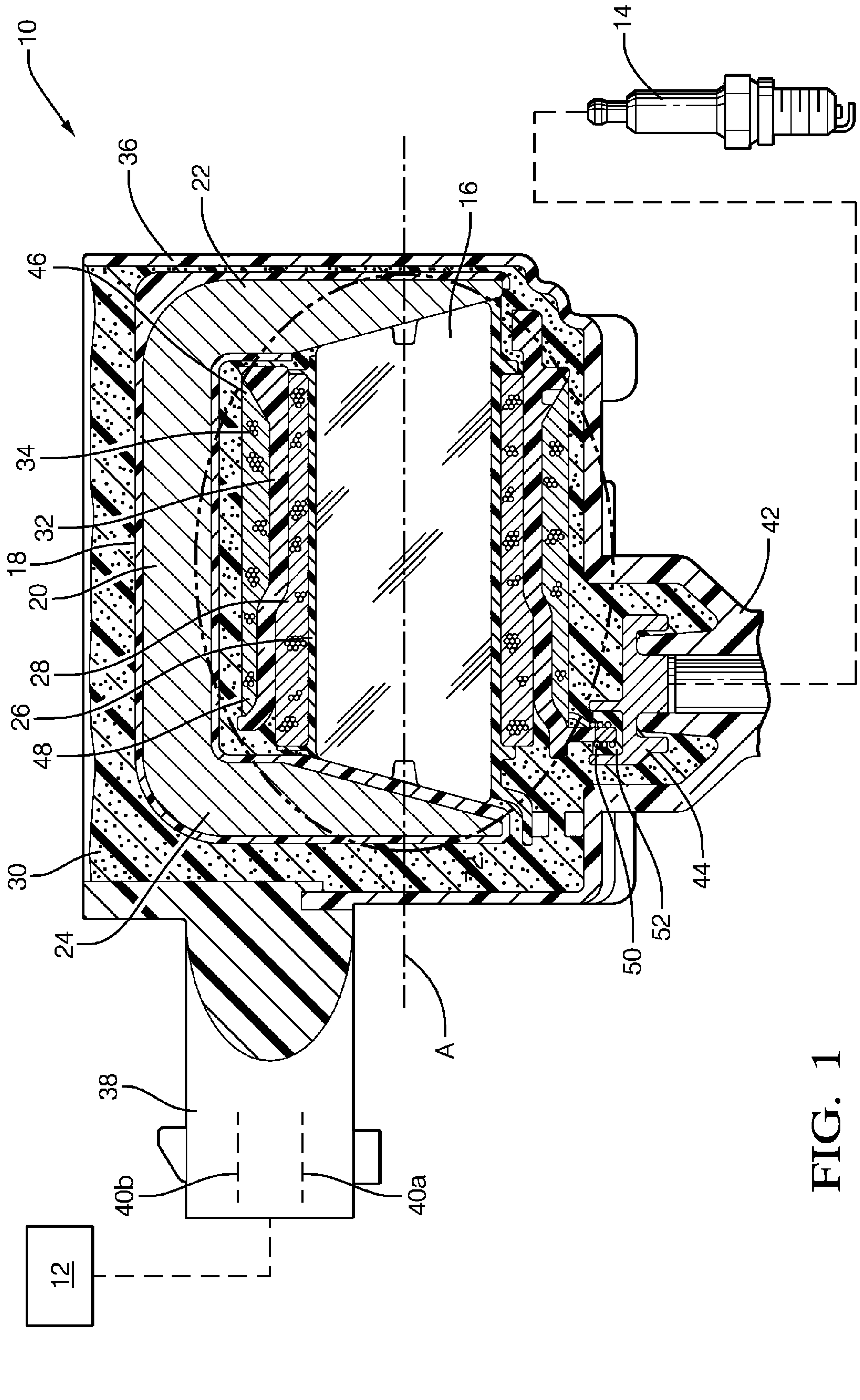
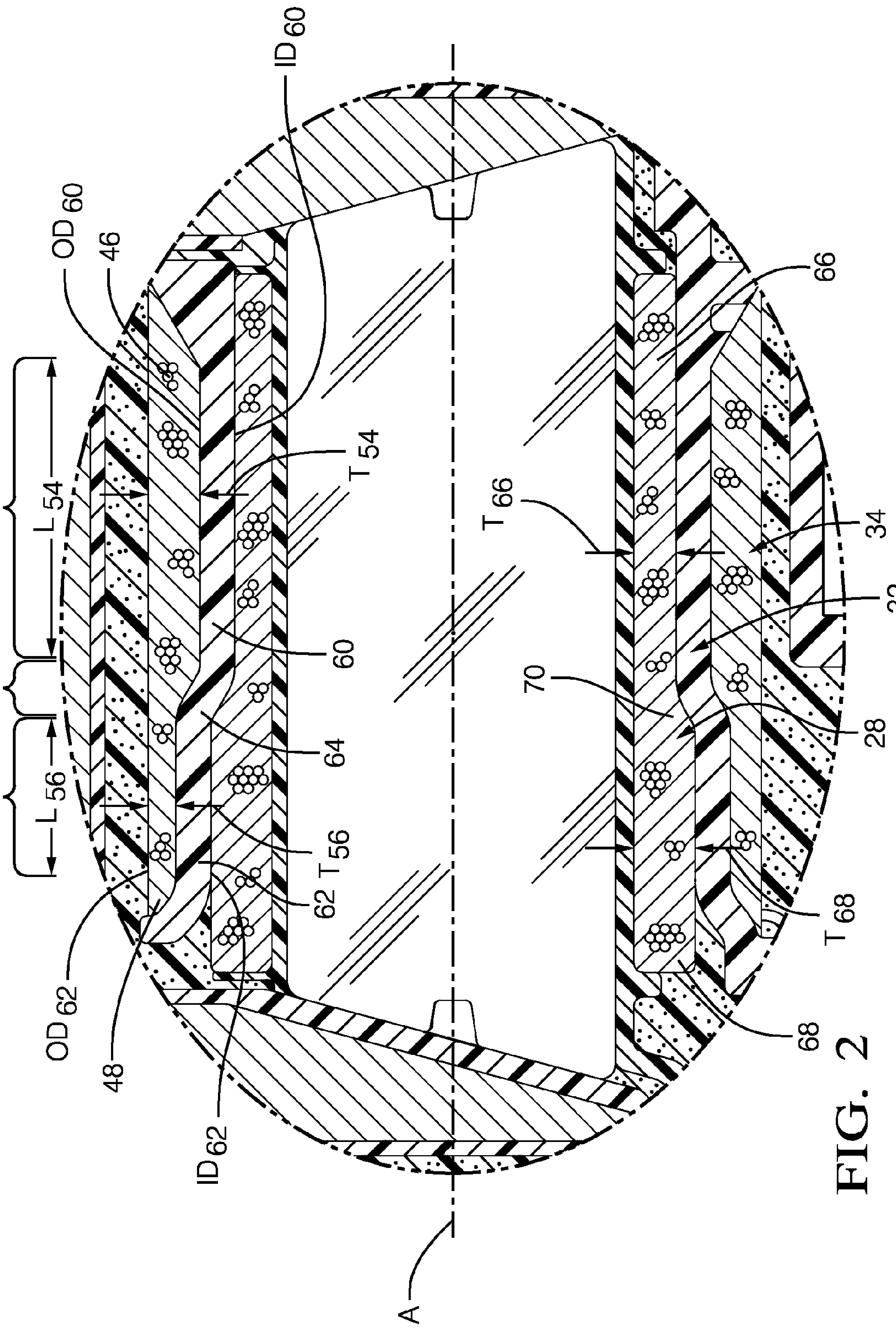


FIG. 1



ID_{60}
OD_{60}
46
66
54
L_{54}
T_{54}
T_{66}
34
32
60
58
70
28
64
56
L_{56}
T_{56}
62
T_{68}
OD_{62}
48
68
ID_{62}
A

FIG. 2

IGNITION COIL

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This patent application claims the benefit of U.S. provisional patent application Ser. No. 62/012,557 filed on Jun. 16, 2014, the disclosure of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD OF INVENTION

The present invention relates to an ignition coil for developing a spark-generating current that is applied to a spark plug and more particularly to such an ignition coil with a secondary winding which maintains an acceptable wire to wire voltage when subjected to a current pulse.

BACKGROUND OF INVENTION

Ignition coils are known for use in connection with an internal combustion engine such as an automobile engine. Ignition coils typically include a core around which is wound a primary winding. A secondary winding is wound around a secondary winding spool to surround the primary winding such that a high voltage is induced on the secondary winding when an electric current applied to the primary winding is stopped. One end of the secondary winding is a low-voltage end which is connected to a ground terminal while the other end of the secondary winding is a high-voltage end which is connected to a high-voltage terminal which is in electrical communication with a spark plug, thereby delivering a spark-generating current to the spark plug. Delivering the spark-generating current to the spark plug results in the first several hundred turns of the high-voltage end of the secondary winding being subjected to a high current pulse. Unless the high current pulse is properly dealt with, the secondary winding may be undesirably affected by the high current pulse.

The high current pulse is most easily limited by using a high resistance spark plug. High resistance spark plugs were common in less-recent internal combustion engines, and consequently, the high current pulse was not of sufficient magnitude to need to be factored into the secondary winding design. However, more modern internal combustion engines are commonly utilizing lower resistance spark plugs in order to boost energy from the coil, thereby resulting in higher voltages and making the high current pulse a magnitude that may not be compatible with the secondary winding.

Another way to deal with the high current pulse is to wind the secondary winding in a segmented winding strategy where a plurality of axially spaced ribs on the secondary winding spool forms a plurality of channels therebetween. Consequently, the secondary winding is divided into segments where the potential difference is minimized between the outermost windings of a given segment and the innermost windings of the given segment. As a result, the potential difference is kept to an acceptable level between the outermost winding and the innermost winding at the high-voltage end of the secondary winding that is subjected to the high current pulse. An example of a secondary winding using such a segmented winding strategy is shown in United States Patent Application Publication No. US 2013/0291844 to Skinner et al., the disclosure of which is incorporated herein by reference in its entirety.

While the segmented winding strategy of United States Patent Application Publication No. US 2013/0291844 to Skinner et al. may be effective for dealing with the high current pulse, it may be desirable to use a progressive winding strategy where the secondary winding is wound uninterrupted around the secondary winding spool. Using the progressive winding strategy may be more desirable than the segmented winding strategy because the axial spaced ribs used to implement the segmented winding strategy add stress to the secondary winding spool and thereby require the secondary winding spool to be made of special material under some circumstances. The progressive winding strategy may be less costly to manufacture due at least in part to requiring less costly material, furthermore, the progressive winding strategy may allow the ignition coil to be made more compact which is particularly important when the ignition coil is a plug-top coil. However, since the progressive winding strategy is wound uninterrupted around the secondary winding spool, the potential difference between the outermost winding and the innermost winding is greater than in the segmented winding strategy. In order to minimize the potential difference between the outermost winding and the innermost winding in the progressive winding, the secondary winding may be increased in axial length, thereby decreasing the thickness of the secondary winding by spreading the number of windings over a greater length, however, this may not be possible to do while maintaining a desired packaging size of the ignition coil. An example of a secondary winding using such a progressive winding strategy is shown in U.S. Pat. No. 6,556,118 to Skinner et al., the disclosure of which is incorporated herein by reference in its entirety.

What is needed is an ignition coil which minimizes or eliminates one or more of the shortcomings as set forth above.

SUMMARY OF THE INVENTION

Briefly described, an ignition coil is provided for delivering a spark-generating current to a spark plug. The ignition coil includes a magnetically-permeable core; a primary winding disposed outward of the core; and a secondary winding radially surrounding the primary winding and inductively coupled to the primary winding, the secondary winding having a low-voltage end and a high-voltage end. The secondary winding includes a secondary winding first section proximal to the low-voltage end and having a first thickness. The secondary winding also includes a secondary winding second section proximal to the high-voltage end and having a second thickness that is less than the first thickness of the secondary winding first section. By having the second thickness less than the first thickness, the potential difference between the outermost winding and the innermost winding, i.e. wire to wire voltage, at the high voltage end can be maintained at an acceptable level while minimizing the axial length of the secondary winding and also minimizing the packaging size of the ignition coil.

Further features and advantages of the invention will appear more clearly on a reading of the following detailed description of the preferred embodiment of the invention, which is given by way of non-limiting example only and with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

This invention will be further described with reference to the accompanying drawings in which:

FIG. **1** is a simplified cross-section view of an ignition coil in accordance with the present invention; and

FIG. **2** is an enlarged portion of FIG. **1**.

DETAILED DESCRIPTION OF INVENTION

Reference will first be made to FIG. **1** which shows a simplified cross-sectional view of an ignition coil **10**. Ignition coil **10** may be controlled by a control unit **12** or the like. Ignition coil **10** is configured for connection to a spark plug **14** that is in threaded engagement with a spark plug opening (not shown) in an internal combustion engine (also not shown). Ignition coil **10** is configured to deliver a high-voltage spark-generating current to spark plug **14**, as shown. Generally, overall spark timing (dwell control) and the like is provided by control unit **12**. One ignition coil **10** may be provided per spark plug **14**.

Ignition coil **10** may include a magnetically-permeable core **16**, a magnetically-permeable structure **18**, hereinafter referred to as high-permeance structure **18**, configured to provide a high permeance magnetic return path which has a base section **20** and a pair of legs **22** and **24**, a primary winding spool **26**, a primary winding **28**, a quantity of encapsulant **30** such as an epoxy potting material, a secondary winding spool **32**, a secondary winding **34**, a case **36**, a low-voltage connector body **38** having primary terminals **40***a*, **40***b* (shown in FIG. **1** as hidden lines), a high-voltage tower **42**, and a high-voltage terminal **44**.

Core **16** extends along a core longitudinal axis A. Core **16** may be made of laminated steel plates, compression molded insulated iron particles, or other appropriate material. Core **16** may be any cross-sectional shape known to those of ordinary skill in the art, for example only, oval or circular.

Primary winding spool **26** is configured to receive and retain primary winding **28**. Primary winding spool **26** is disposed adjacent to and radially outward of core **16** and is preferably in coaxial relationship therewith. Primary winding spool **26** may comprise any one of a number of conventional spool configurations known to those of ordinary skill in the art. In the illustrated embodiment, primary winding spool **26** is configured to receive one continuous primary winding. Primary winding spool **26** may be formed generally of electrical insulating material having properties suitable for use in a relatively high temperature environment. For example, primary winding spool **26** may comprise plastic material such as PPE/PS (e.g., NORYL® available from SABIC) or polybutylene terephthalate (PBT) thermoplastic polyester. It should be understood that there are a variety of alternative materials that may be used for primary winding spool **26**.

Primary winding **28**, as described above, is wound onto primary winding spool **26**. Primary winding **28** includes first and second ends that are connected to the primary terminals **40***a*, **40***b* in low-voltage connector body **38**. Primary winding **28** is configured to carry a primary current I_P for charging ignition coil **10** upon control of control unit **12**. Primary winding **28** may comprise copper, insulated magnet wire, with a size typically between about 20-23 AWG. Further features of primary winding **28** will be described in greater detail later.

Secondary winding spool **32** is configured to receive and retain secondary winding **34**. Secondary winding spool **32** is disposed adjacent to and radially outward of the central components comprising core **16**, primary winding spool **26** and primary winding **28** and, preferably, is in coaxial relationship therewith. Secondary winding spool **32** is configured to receive secondary winding **34** in a continuous winding strategy (e.g., progressive winding) where secondary winding **34** is wound uninterrupted around secondary winding spool **32**. Secondary winding spool **32** may be formed generally of electrical insulating material having properties suitable for use in a relatively high temperature environment. For example, secondary winding spool **32** may comprise plastic material such as PPE/PS (e.g., NORYL available from SABIC) or polybutylene terephthalate (PBT) thermoplastic polyester. It should be understood that there are a variety of alternative materials that may be used for secondary winding spool **32**. Further features of secondary winding spool **32** will be described in greater detail later.

Secondary winding **34** includes a low-voltage end **46** and a high-voltage end **48**. Low-voltage end **46** may be electrically connected to a low-voltage terminal (not shown) within case **36** which is connected to ground by way of a ground connection through low-voltage connector body **38**. High-voltage end **48** is electrically connected to high-voltage terminal **44** through a high-voltage end termination **50** which is disposed within electrically conductive epoxy **52** which is electrical contact with high-voltage terminal **44**. Alternatively, high-voltage end termination **50** may be connected to high-voltage terminal **44** with a soldered connection or other known connection method. Secondary winding **34** may be implemented using conventional material (e.g. copper, insulated magnet wire) known to those of ordinary skill in the art. Further features of secondary winding **34** will be described in greater detail later.

High-permeance structure **18** is configured to provide a high permeance magnetic return path for the magnetic flux produced in core **16** during operation of ignition coil **10**. High-permeance structure **18** may be formed, for example, from a stack of silicon steel laminations or other adequate magnetic material. As described previously, high-permeance structure **18** includes base section **20** and a pair of legs **22** and **24**. Core **16** is positioned between legs **22** and **24** such that core longitudinal axis A passes through legs **22** and **24**. One end of core **16** mates with leg **22** while the other end of core **16** forms a gap with leg **24** where the gap may be in a range of, for example only, about 0.5 mm to 2 mm. Further features of high-permeance structure **18** are described in United States Patent Application Publication No. 2013/0291844 A1 to Skinner et al., the disclosure of which is incorporated herein by reference in its entirety.

Encapsulant **30** may be suitable for providing electrical insulation within ignition coil **10**. In a preferred embodiment, encapsulant **30** may comprise an epoxy potting material. Sufficient encapsulant **30** is introduced in ignition coil **10**, in the illustrated embodiment, to substantially fill the interior of case **36**. Encapsulant **30** also provides protection from environmental factors which may be encountered during the service life of ignition coil **10**. There are a number of encapsulant materials known in the art.

Reference will continue to be made to FIG. **1** and additional reference will now be made to FIG. **2** which shows an enlarged portion of primary winding **28**, secondary winding spool **32**, and secondary winding **34**. Secondary winding **34** includes a secondary winding low-voltage section **54**, hereinafter referred to as secondary winding first section **54**, that is proximal to low-voltage end **46**. Secondary winding first section **54** has a substantially uniform thickness T_{54} in the radial direction and a length L_{54} in the direction of axis A. Secondary winding **34** also includes a secondary winding high-voltage section **56**, hereinafter referred to as secondary winding second section **56**, that is proximal to high-voltage end **48**. Secondary winding second section **56** has a substantially uniform thickness T_{56} in the radial direction and a length L_{56} in the direction of axis A such that thickness T_{56} is less than thickness T_{54}. Consequently, secondary winding second section **56** has fewer layers of windings in the radial direction than secondary winding first section **54** has in the radial direction. A secondary winding third section **58** may connect secondary winding first section **54** to secondary winding second section **56** such that the thickness in the radial direction of secondary winding third section **58** tapers from thickness T_{54} to thickness T_{56} in a substantially uniform manner. Length L_{56} and thickness T_{56} are selected to achieve an acceptable potential difference (i.e. wire to wire voltage) between the outermost winding of secondary winding **34** and the innermost winding of secondary winding **34** when subjected to a high current pulse when ignition coil **10** supplies the spark-generating current to spark plug **14**. Length L_{54} and length L_{56} are preferably each at least 5% of the total length of secondary winding **34**.

Secondary winding spool **32** may be configured to achieve the difference in thickness T_{54} and thickness T_{56}. More specifically, secondary winding spool **32** may include a secondary winding spool first section **60** having an outside diameter OD_{60} around which secondary winding first section **54** is wound and an inside diameter ID_{60} that is radially inward of outside diameter OD_{60}. Secondary winding spool **32** may also include a secondary winding spool second section **62** having an outside diameter OD_{62} around which secondary winding second section **56** is wound and an inside diameter ID_{62} that is radially inward of outside diameter OD_{62}. Secondary winding spool **32** may also include a secondary winding spool third section **64** which tapers from outside diameter OD_{60} to outside diameter OD_{62} around which secondary winding third section **58** is wound. Outside diameter OD_{62} is larger than outside diameter OD_{60}, and consequently, when secondary winding **34** is wound on secondary winding spool **32**, secondary winding **34** may have an external diameter that is substantially uniform for the entire length of secondary winding **34** in order to allow thickness T_{56} to be less than thickness T_{54}.

Inside diameter ID_{62} of secondary winding spool second section **62** may be greater than inside diameter ID_{60} of secondary winding spool first section **60**, consequently, primary winding **28** may include a primary winding first section **66** that is radially surrounded by secondary winding spool inside diameter ID_{60} of secondary winding spool first section **60** and a primary winding second section **68** that is radially surrounded by inside diameter ID_{62} of secondary winding spool second section **62**. As a result, primary winding first section **66** has a substantially uniform thickness T_{66} in the radial direction while primary winding second section **68** has a substantially uniform thickness T_{68} in the radial direction which is greater than thickness T_{66}. A primary winding third section **70** connects primary winding first section **66** to primary winding second section **68**, and consequently, primary winding third section **70** tapers from thickness T_{66} to thickness T_{68}. Since inside diameter ID_{62} of secondary winding spool second section **62** is greater than inside diameter ID_{60} of secondary winding spool first section **60**, primary winding **28** can include more windings than if inside diameter ID_{62} was the same as inside diameter ID_{60}, thereby increasing the efficiency of ignition coil **10**.

By having thickness T_{56} of secondary winding second section **56** less than thickness T_{54} of secondary winding first section **54**, the potential difference between the outermost winding and the innermost winding at high-voltage end **48** of secondary winding **34** can be maintained at an acceptable level while minimizing the axial length of the secondary winding **34** and also minimizing the packaging size of the ignition coil **10**.

While secondary winding spool **32** has been illustrated as having outside diameter OD_{60} and outside diameter OD_{62} which is larger than outside diameter OD_{60}, it should now be understood that secondary winding spool **32** may have a substantially uniform outside diameter (not shown), i.e. outside diameter OD_{60} and outside diameter OD_{62} are equal, around which secondary winding first section **54** and secondary winding second section **56** are wound. When secondary winding first section **54** and secondary winding second section **56** are wound around a portion of secondary winding spool **32** that is uniform in diameter, thickness T_{56} of secondary winding second section **56** that is less than thickness T_{54} of secondary winding first section **54** is achieved by simply winding secondary winding first section **54** with more windings than secondary winding second section **56**.

While secondary winding **34** has been illustrated with two sections of differing thicknesses, i.e. secondary winding first section **54** and secondary winding second section **56**, it should now be understood that one or more additional sections of distinct thickness may be provided.

While a specific configuration of ignition coil **10** has been described, it should be understood that the present invention is applicable for use in a variety of ignition coil configurations.

While this invention has been described in terms of preferred embodiments thereof, it is not intended to be so limited, but rather only to the extent set forth in the claims that follow.

We claim:

1. An ignition coil for delivering a spark-generating current to a spark plug; said ignition coil comprising:
- a magnetically-permeable core;
- a primary winding disposed outward of said core; and
- a secondary winding radially surrounding said primary winding and inductively coupled to said primary winding, said secondary winding having a low-voltage end and a high-voltage end;
- wherein said secondary winding includes a secondary winding first section proximal to said low-voltage end and having a secondary winding first thickness and wherein said secondary winding also has a secondary winding second section proximal to said high-voltage end and having a secondary winding second thickness that is less than said secondary winding first thickness.

2. An ignition coil as in claim **1** wherein said secondary winding first thickness is substantially uniform and said secondary winding second thickness is substantially uniform.

3. An ignition coil as in claim **1** where said secondary winding includes a secondary winding third section between said secondary winding first section and said secondary winding second section, said secondary winding third section tapering in thickness from said secondary winding first thickness to said secondary winding second thickness.

4. An ignition coil as in claim **3** wherein said secondary winding has a substantially uniform external diameter over said secondary winding first section, said secondary winding second section, and said secondary winding third section.

5. An ignition coil as in claim **1** wherein said secondary winding has a substantially uniform external diameter over said secondary winding first section and said secondary winding second section.

6. An ignition coil as in claim **1** further comprising a secondary winding spool, wherein:
- said secondary winding spool has a secondary winding spool first section around which said secondary winding first section is wound, said secondary winding spool first section having a first outside diameter;

said secondary winding spool has a secondary winding spool second section around which said secondary winding second section is wound, said secondary winding spool second section having a second outside diameter which is larger than said first outside diameter.

7. An ignition coil for delivering a spark-generating current to a spark plug; said ignition coil comprising:

a magnetically-permeable core;

a primary winding disposed outward of said core;

a secondary winding radially surrounding said primary winding and inductively coupled to said primary winding, said secondary winding having a low-voltage end and a high-voltage end; and

a secondary winding spool; wherein:

said secondary winding includes a secondary winding first section proximal to said low-voltage end and having a secondary winding first thickness and wherein said secondary winding also has a secondary winding second section proximal to said high-voltage end and having a secondary winding second thickness that is less than said secondary winding first thickness;

said secondary winding spool has a secondary winding spool first section around which said secondary winding first section is wound, said secondary winding spool first section having a first outside diameter;

said secondary winding spool has a secondary winding spool second section around which said secondary winding second section is wound, said secondary winding spool second section having a second outside diameter which is larger than said first outside diameter;

said secondary winding spool first section has a first inside diameter; and

said secondary winding spool second section has a second inside diameter which is larger than said first inside diameter.

8. An ignition coil as in claim **7** wherein:

said primary winding has a primary winding first section which is radially surrounded by said first inside diameter and which is substantially uniform in thickness;

said primary winding has a primary winding second section which is radially surrounded by said second inside diameter and which is substantially uniform in thickness.

9. An ignition coil as in claim **8** wherein said primary winding second section is thicker than said primary winding first section.

10. An ignition coil as in claim **9** wherein said primary winding has a primary winding third section which is between said primary winding first section and said primary winding third section and which tapers in thickness from said primary winding first section to said primary winding second section.

11. An ignition coil as in claim **1** wherein:

said primary winding includes a primary winding first section having a primary winding first thickness; and

said primary winding has a primary winding second section having a primary winding second thickness that is greater than said primary winding first thickness.

12. An ignition coil for delivering a spark-generating current to a spark plug; said ignition coil comprising:

a magnetically-permeable core;

a primary winding disposed outward of said core; and

a secondary winding radially surrounding said primary winding and inductively coupled to said primary winding, said secondary winding having a low-voltage end and a high-voltage end; wherein:

said secondary winding includes a secondary winding first section proximal to said low-voltage end and having a secondary winding first thickness and wherein said secondary winding also has a secondary winding second section proximal to said high-voltage end and having a secondary winding second thickness that is less than said secondary winding first thickness;

said primary winding includes a primary winding first section having a primary winding first thickness;

said primary winding has a primary winding second section having a primary winding second thickness that is greater than said primary winding first thickness;

said secondary winding first section radially surrounds said primary winding first section; and

said secondary winding second section radially surrounds said primary winding second section.

13. An ignition coil for delivering a spark-generating current to a spark plug; said ignition coil comprising:

a magnetically-permeable core;

a primary winding disposed outward of said core; and

a secondary winding radially surrounding said primary winding and inductively coupled to said primary winding, said secondary winding having a low-voltage end and a high-voltage end; wherein:

said secondary winding includes a secondary winding first section proximal to said low-voltage end and having a secondary winding first thickness and wherein said secondary winding also has a secondary winding second section proximal to said high-voltage end and having a secondary winding second thickness that is less than said secondary winding first thickness;

said primary winding includes a primary winding first section having a primary winding first thickness;

said primary winding has a primary winding second section having a primary winding second thickness that is greater than said primary winding first thickness;

said secondary winding first thickness is substantially uniform;

said secondary winding second thickness is substantially uniform;

said primary winding first thickness is substantially uniform; and

said primary winding second thickness is substantially uniform.

14. An ignition coil as in claim **13** wherein:

said secondary winding first section radially surrounds said primary winding first section; and

said secondary winding second section radially surrounds said primary winding second section.

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